



## Sonder la matière par les ondes électromagnétiques

### *Exploring the hidden structures and properties of the Solar System's planets and bodies with radars*

**Valérie Ciarletti**

UVSQ (UPSay); UPMC (Sorbonne Univ.); CNRS/INSU; LATMOS-IPSL, Guyancourt, France

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#### Résumés

Depuis les premières observations de la Lune depuis la Terre avec un radar en 1946, les radars font de plus en plus fréquemment partie de la charge utile des missions d'exploration du système solaire. Ils sont, en effet, les seuls instruments à pouvoir recueillir, à partir de plateformes en orbite des informations sur la structure superficielle d'un corps ou d'une planète à travers des atmosphères opaques (mission MAGELLAN pour Venus et mission CASSINI pour Titan), ou sonder le sous-sol d'une planète à travers sa surface (radar MARSIS de la mission MarsExpress et SHARAD de la mission Mars Reconnaissance Orbiter pour Mars). Très récemment, la mission Rosetta a permis de mettre en œuvre le radar bistatique CONSERT qui a été conçu pour étudier la structure interne du noyau de la comète 67P/Churyumov-Gerasimenko. Les prochaines missions ExoMars (ESA/Roskosmos, 2018) et Mars2020 (NASA, 2020) poseront chacune à la surface de Mars un véhicule équipé d'un radar à pénétration de sol. Des informations capitales pour comprendre l'histoire géologique des sites d'atterrissage seront fournies par ces GPR. Une revue des résultats obtenus par ces différents radars scientifiques sera présentée dans cet article.

Since the very first observations of the Moon from the Earth with radar in 1946, radars are more and more frequently selected to be part of the payload of exploration missions in the solar system. They are, in fact, the only instruments that can collect, from platforms in orbit, information on the surface structure of a body or planet hidden by an opaque atmosphere (Radars of the Magellan Mission for Venus and of the Cassini mission for Titan) or probe the planet subsurface through its surface (radar onboard the MarsExpress and Mars Reconnaissance Orbiter missions to Mars). Very recently, the Rosetta mission operated a bistatic radar designed to study the internal structure of a comet nucleus. The preliminary results obtained so far validate the instrument concept and allow to gather information about 67P / Churyumov-Gerasimenko's nucleus. The next ExoMars mission (ESA / Roskosmos, 2018) and Mars2020 mission (NASA, 2020) will both land at the surface of Mars a vehicle equipped with a ground-penetrating radar. Essential information for understanding the geological history of landing sites will be provided by these instruments.

A brief review of radars designed for the Solar System planets and bodies' exploration is presented in the paper. This review does not aim at being exhaustive but will focus on the major results obtained and will exclude atmospheric radar studies.

#### Introduction:

Radars have a unique capacity to provide remotely information about targets that cannot be reached by other kinds of instruments. In planetary science, they have been successfully used to reveal the topography of the surface of a solar system's body hidden by a thick atmosphere (Impact craters and volcanos on Venus, Lakes and possible cryovolcanos on Titan), the structures and layers buried under the surface of a planet giving thus access to its geological history (Layering inside the Polar caps of Mars, Thickness of lava flows on the Moon) or even the internal structure of a small body (Churyumov-Gerasimenko).

The basic principle of radars is simple: it is based on the transmission and eventually reception of an electromagnetic wave that has propagated through and interacted with the sounded environment. After more or less complicated signal processing, the radar determines for each detected echo a propagation delay and its associated amplitude. Both quantities

are then processed to retrieve information on the geometrical and the dielectric properties of the target and of the propagation environment between the target and the antennas. The instrument's final radiometric performances depends on the radar's parameters, on the geometrical configuration, on the sounded environment properties and on the optimal use made on the redundancy within the measurements.

Section 1 of this paper presents the main kinds of radars that have been used to explore the solar system's bodies and planets. The emphasis is put on the platforms those radars can accommodated on (i.e. spacecraft in orbit or flyby, rover mobile at the surface, and even stationary lander on the surface) radar and on the choice of a center frequency according to the scientific and technical objectives to reach.

An overview of the main radar experiments designed for planetary exploration and some of the most significant results they obtained are presented in the second section.

The last section is dedicated to the CONSERT experiment that has been very recently operated on the Rosetta mission to comet Churyumov-Gerasimenko.

## 1. Radars for planetary exploration and science

Radars were originally developed for military purposes, which has rapidly contributed to the development of a number of civil applications for safe travel and remote sensing of the Earth environment. For decades now, the famous radar equation has been the basis to design radars [1], especially for planetary exploration where distances to the targets are often extremely large and where very little information is available on the target's characteristics.

### 1.1. Choosing the platform

The first historic observations of the Moon have been made from the Earth in 1946 at 138 MHz by the Corps' Evans Signal Laboratory, New Jersey [2], [3]. After some unsuccessful attempts, in 1961, Venus became the first planet of the solar system to be explored by a radar from the Earth, the 34-m dish of the Goldstone Observatory in California [4], [5] was used at first followed later by the 300-m diameter antenna at Arecibo [6].

Since the 1980, the vast majority of radars used in planetary science have been operated on missions that offered the opportunity to map the whole planet from orbit (the MarsExpress [7] and Mars Reconnaissance Orbiter [8] missions around Mars, the Magellan mission to Mercury [9]) or during a number of limited flybys (the Cassini mission to Saturn and its moons [10]) Nevertheless, radars dedicated to a more accurate but local subsurface characterization can be accommodated on board a vehicle mobile at the planet's surface. The recent Chang'e-3 mission [11] landed on the Moon a rover equipped with a Ground Penetrating Radar (GPR) in order to sound the lunar regolith from the surface. The next ESA and NASA rover missions to Mars, ExoMars [12] and Mars2020 will also operate a GPR to sound the Martian subsurface along the rover's path.

Less conventional experiments have been specifically designed to retrieve information on the subsurface structure and its dielectric properties in very specific context. Among those, we can mention two bi-static radars:

The CONSERT experiment of the Rosetta mission aiming at the tomography of the comet's nucleus, is composed of two separated units, the first one is located on the surface of the nucleus while the other one is on-board the orbiter [13]. The last section of this paper is dedicated to the CONSERT experiment.

The EISS (Electromagnetic Investigation of the Sub-Surface) bistatic radar was selected on the now canceled Humboldt payload of the ExoMars mission. The instrument is able to take advantage of the simultaneous presence of a stationary lander and a mobile rover to perform deep sounding of the Martian subsurface around the landing site. In monostatic mode, the long electrical antennas located on the stationary platform of the mission are used for transmission and reception. While in Bistatic mode, a magnetic receiver accommodated on the mission's rover, is able to measure three orthogonal components of the magnetic field too. These measurements allow to retrieve the direction of arrival of each reflected waves and thus to retrieve the 3D location of the buried reflecting structures for a better understanding of the geological context of the site [14] [15].

Finally, on a number of space missions, opportunity bi-static experiments that take advantage of existing communication channel of the spacecraft with Earth, can perform limited soundings of the planet's subsurface at grazing incidence angles (for example, the Mars Radio Science experiment [16] on-board the MarsExpress spacecraft, the Clementine bi-static radar experiment at the Moon [17] and the Viking bistatic radar on Mars [18])

### 1.2. Designing the right radar

The specifications for each instrument of a mission payload is based on the scientific objectives of the mission. For a radar, the characteristics of the target (range, geoelectrical and geometrical properties) as well as the final product (image, topography, estimated roughness and dielectric properties, subsurface characterization) and resolution aimed at, will guide the radar design.

#### 1.2.1. A variety of operating modes

Most of the time, given the limited resources (of mass, volume and power) available in space missions, radars designed and developed for planetary missions are adaptable enough that they can be operated in different modes making the best way of the hardware. They very often can be used as altimeter, synthetic-aperture radar, subsurface sounder, scatterometer, radiometer and often also used to characterize the atmosphere and ionosphere as well when relevant.

A radar altimeter is usually a nadir-looking radar. It measures the power received after interaction with the surface as a function of the propagation delay and thus provides an estimate of the distance between the radar and the reflecting surface. It is used to obtain a topography of the surface. The radar altimeter echo profile is controlled by the range to the surface

and the surface back-scattering properties which depend on the surface roughness at scales larger than the wave length and on the dielectric properties of the shallow subsurface. The frequency of the radar altimeter is usually chosen high enough to limit penetration into the subsurface.

On the contrary, soundings radars are low-frequency HF Ground-Penetrating Radars. They used to perform deep soundings (up to several hundreds of meters) of the planet sub-surface structure. The first radar sounder flown was ALSE [19] (Apollo Lunar Sounder Experiment) on board Apollo 17 in 1972. Two other sounders have explored the Martian sub-surface (§ 3.1.1): MARSIS (Mars Advanced Radar for SubSurface and Ionosphere Sounding) [20] on board the European Space Agency's Mars Express probe, and SHARAD (mars SHAlow RADar sounder) [21] on the NASA Mars Reconnaissance Orbiter (MRO). A radar sounder has also been used on the Japanese moon probe SELENE [22], launched in 2007 (§ 3.1.2).

A synthetic-aperture radar (SAR) is used to obtain images of an area at a wave length which is significantly lower than those used by common cameras. It uses the motion of the antenna over an area to improve the spatial resolution, as a consequence, SAR are typically mounted on a moving spacecraft but then might also be used on a moving/rotating target. Synthetic aperture radars are the only instruments able to provide images of a planet's surface hidden by an opaque atmosphere like Venus and Titan. The two Soviet spacecrafts Venera 15 and Venera 16 [23] provided images of the planet in 1983 using SAR and Radar altimeters. The SAR of the Magellan mission [24] later in 1990 achieved an almost complete coverage of the surface of Venus (§ 2.1.1). The SAR of the Cassini [25] spacecraft, in orbit around Saturn, has provided impressive images of Titan surface during flybys (§ 2.1.2). When possible, enhanced processing of SAR data allow to build SAR-based topography of a surface with a much better resolution than the one obtained by simple radar altimeter.

### 1.2.2. A broad frequency range

The choice of the frequency is of the uppermost importance since it will drive the penetration depth. Moreover, because the bandwidth is limited by the central frequency, this choice will also set the range resolution of the instrument. In the context of planetary missions, radars operating at extremely different frequency have been used for planetary exploration (see Fig.1). The largest wavelength has been used by the MARSIS sounder onboard the MarsExpress ESA mission: 230 m in the vacuum for a radar aiming at kilometric penetration depths to search for potential liquid water reservoirs in the Martian Subsurface. The shortest is 2.18 cm for the radar of the Cassini mission whose primary objective is to characterize the Titan's surface through a thick atmosphere.

The choice of the center frequency has also an impact on the radar range resolution since the larger the frequency band width, the better the resolution is. As a consequence, if radars designed to perform deep sounding of the subsurface must operate at low center frequency, they will have a poor vertical resolution. On the other side, radar operating at higher frequency might have a much better range resolution but very limited penetration. Comparison of the MARSIS and ShaRad sounders operated on Mars is a good illustration of the matter (Fig. 3).

In addition to these considerations, in the specific context of a space mission, where the

size and mass of the payload's instruments are always strongly limited, the size of the antenna used to transmit and receive the electromagnetic waves and hence choice of the frequency is further constrained.

## 2. A variety of targets in the Solar System

The radar investigations of the solar system started logically with Earth-based observations and aimed at the closest targets to Earth, namely the Moon. Next came Venus and Mercury, followed by Mars and the Moons of Saturn. Soon the moons of Jupiter will also be explored by radars. This section illustrates the impressive knowledge that has been acquired on the solar system thanks to radar instruments.

### 2.1. Peering through a dense and opaque atmosphere

Radars have been successfully used to reveal the topography and geological features of the surface of a solar system's body through a thick and opaque atmosphere. Venus and Titan's exploration by radars provide the best illustrations of this radar capacity.

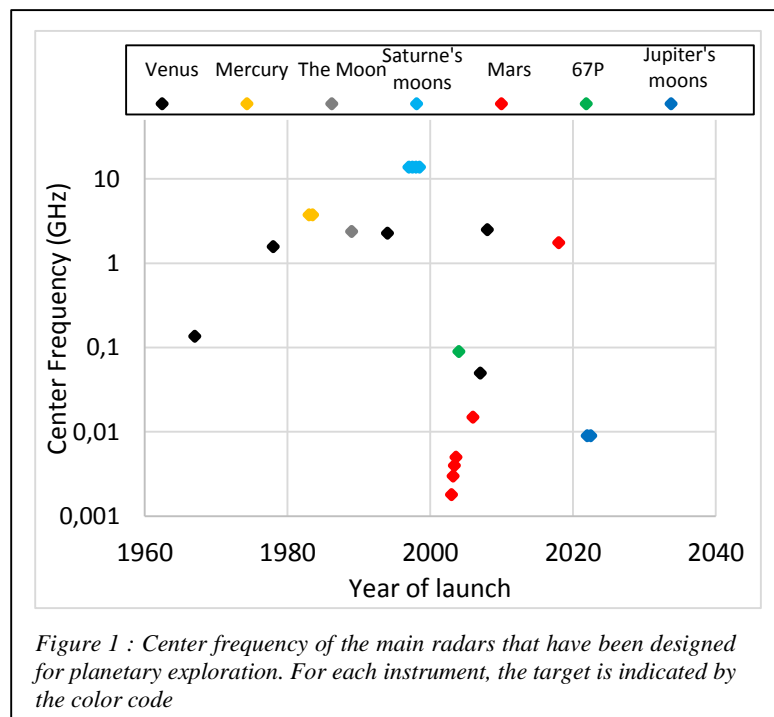


Figure 1 : Center frequency of the main radars that have been designed for planetary exploration. For each instrument, the target is indicated by the color code

### 2.1.1. Venus

Venus' surface is hidden by thick clouds of sulfuric acid that prevent optical remote sensing techniques to access to the surface. Venera was a series of 16 flyby, orbital, and landed missions to Venus conducted by the Soviet Union from 1961 to 1983 to gather information on the planet. Most of these Venera missions failed because of the harsh Venusian environment. But since Venera 7, successful landings of modules able to survive for 30 to 120 minutes at the surface of Venus provided the first pictures of the Venusian ground.

The NASA Pioneer Venus Orbiter was launched in 1978 [26]. One of the main experiment on its payload was the radar (ORAD) operating at 1.757 GHz. This radar altimeter was used to get information on the surface topography which has been reconstructed with an accuracy of 150 m. The surface electrical conductivity and roughness at 1-meter scale have been estimated too. The Pioneer Venus Orbiter was the first spacecraft to use radar to obtain a global image of the Venus surface [27].

In 1983, the twin Venera 15 and 16 spacecrafts carried a radar altimeter and a SAR operating at 3.75 GHz that was used to map and determine the topography of the surface of Venus (from 30 N latitude up to the North Pole) [28]. The achieved vertical resolution was around 230m.

Finally, the Magellan spacecraft [29] was launched by NASA in 1989. The radar on-board [30] collected SAR images, combined with altimetry and radiometry measurements at a frequency of 2.3GHz, over the majority of Venus' surface. The resolution of the SAR was about 150 m. The resolution of the altimeter was 30 m. Combining all the information available a map of the elevation was built for the whole planet (see Fig 2/center). The SAR of the Magellan spacecraft also provided very detailed images [31] (see Fig 2/right) of volcanic structures that revealed that Venus' geology is dominated by volcanism. The impact craters that were detected too, appeared to be evenly spread over Venusian surface, which implies that the planet's entire surface is the same age. The crater counting suggests an age of 1 billion years old

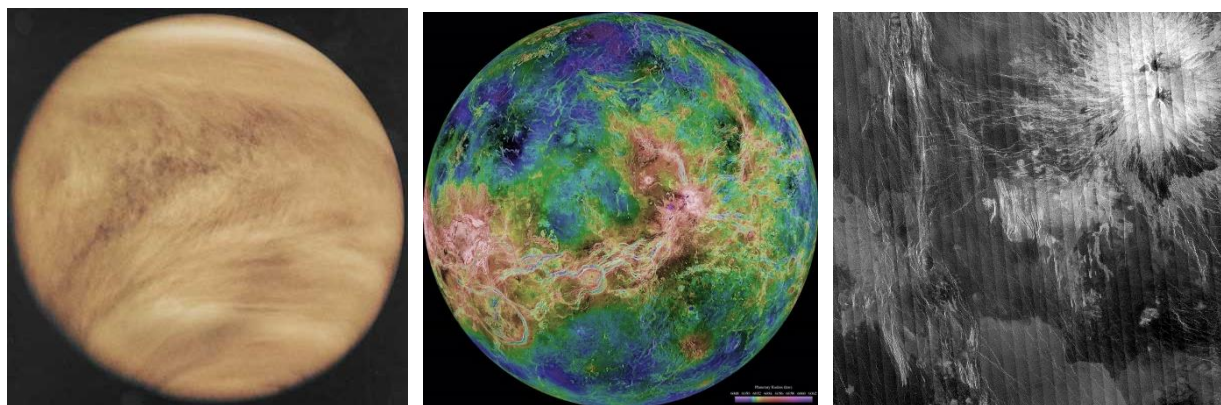


Figure 2 : Images of Venus Credit: NASA/JPL/USGS.

Left: Ultraviolet image by the Pioneer Venus Orbiter spacecraft. This image reveals structures of the atmosphere that are not detected in the visible light image but the surface remains hidden. Center: Topography of surface based on the Magellan radar's data with additional information from Venera and Pioneer Venus missions and Earth-based radar measurements. The lowest elevations are in blue. Right: Image of a 1.5 km-high volcano with a resolution of ~675m obtained by the Magellan SAR:

### 2.1.2. Titan

The Cassini NASA mission was launched in 2005 to explore Saturn, its rings and satellites. A special attention was paid to Titan, which is the only moon in the Solar System with a thick atmosphere (10 times thicker than the Earth's one) that prevents observation in natural-light of its surface. The Huygens ESA probe successfully landed on its surface while the main spacecraft remained in orbit around Saturn. Impressive sets of radar data have been collected during more than one hundred flybys of Titan. The radar on-board the orbiter [25] is a powerful multimode system that can operate as a SAR, radar altimeter, scatterometer and radiometer. Its principal objective is to characterize the surface of Titan on a regional scale. The obtained SAR images with a resolution  $>350\text{m}$  have shown the existence of lakes and seas of Ethane and Methane on the Northern hemisphere (see Fig. 3/center) [32]. Overlapping SAR images have been used locally to build SAR digital elevation models by radar stereogrammetry [33]. The achieved resolution is of several kilometers horizontally and around 100m vertically, which is significantly better than the altimeter's capacity (see Fig. 3/right).



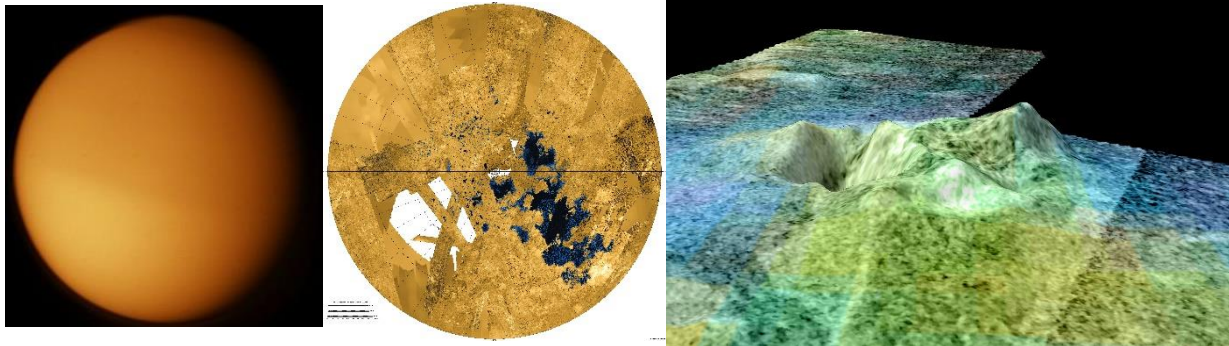


Image credit Voyager Project, NASA/

Image credit: NASA/JPL-Caltech  
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Image Credit: NASA/JPL-Caltech/Space Science Institute

Figure 3: Images of Titan : Left: Visible light image of Titan by Voyager 1 in 1980. A thick orange haze prevents any view of the surface. Center: Colorized mosaic of Titan's northern land of lakes and seas obtained by the multimode radar. The dry areas are displayed in brown and the liquid hydrocarbon in blue.

Right: 3D representation of the Sotra Facula area, that might be the best case for a more than 1-km high cryovolcano.

The radar observations also revealed the presence of numerous impact craters, dunes whose size and pattern vary according with altitude and latitude. [34] (Fig. 4) on Titan as well as river channels.

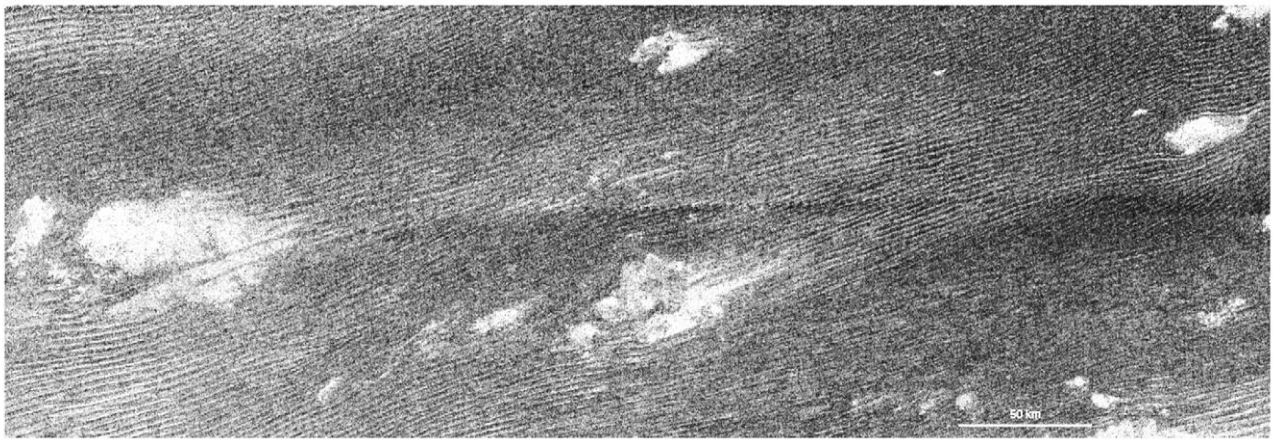


Figure 4: Example of dune on Titan. The dunes of Belet [34] Image Credit NASA/JPL-Caltech

## 2.2. Sounding the sub-surface

Unlike Titan and Venus's surface, the surface of Mars, Mercury and the Moon are readily accessible to optical remote sensing from orbit but radar operated at low enough frequency have the unique capacity to sound through the surface and access to the buried structures.

### 2.2.1. The Sub-surface of Mars

The rare clouds present in the Martian atmosphere do not prevent optical remote sensing of the surface from orbit and there are actually available large data sets obtained by spectrometers, context and high resolution stereoscopic cameras. Nevertheless radars operated at low enough frequency have the unique capacity to sound through the surface and access to the buried structures. Two orbital radars have been designed to retrieve information about the Martian Subsurface. The MARSIS orbital radar sounder, onboard ESA's Mars Express spacecraft launched in 2003, was designed to investigate the Martian ionosphere and the geological and hydrological structure of the subsurface, with a particular emphasis on the potential detection of deep groundwater [35]. MARSIS operates at frequencies of  $\sim 2\text{--}5$  MHz; its horizontal resolution of the instrument is around 10 km while the range resolution is 150 m in vacuum [36]. The particularly low frequencies used by the instrument gives it a theoretical ability to detect the presence of liquid water, under ideal sounding conditions, at depths of up to  $\sim 3\text{--}5$  km beneath the Martian surface [37]. In practice, MARSIS has achieved this level of sounding performance only in select environments, which include the ice-rich (and, thus, low dielectric loss) north and south polar caps (see Fig.5) where it provided estimates the thickness of the ice deposit at the poles, as well as several other sites at

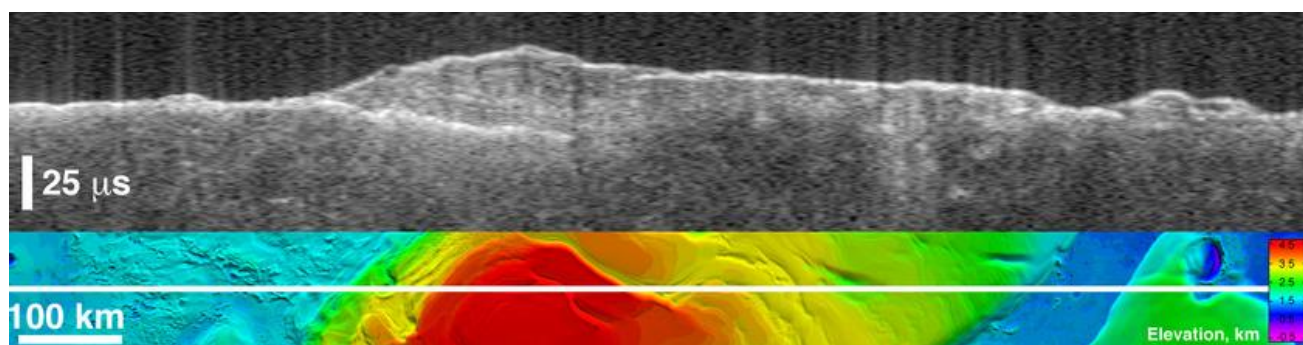


Image Credit : NASA / JPL / ASI / ESA / Univ. of Rome / MOLA Science Team

Figure 5:

Top: MARSIS radargram of the South Pole area

Bottom: The lower image shows the corresponding ground track (white line) on a topographic map of the area based on data from the MOLA laser altimeter on board NASA's Mars Global Surveyor.

lower latitudes. Of the latter, the most notable is the Medusae Fossae Formation, whose radar propagation characteristics are consistent with a composition ranging from a dry, high-porosity pyroclastic deposit at one extreme to an ice-rich sedimentary deposit at the other, potentially formed by the redistribution of polar volatiles at times of high obliquity [38]. Hints of several other moderately deep reflectors have also been found in the vicinity of Ma'adim Vallis, where there is evidence that they may originate from lithologic interfaces [39].

MARSIS was closely followed by the flight of another radar sounder called the SHallow RADar (SHARAD) on the Mars Reconnaissance Orbiter (MRO) [40]. SHARAD was designed to complement the capabilities and performance of MARSIS by operating at higher frequencies around 20 MHz to better resolve variations in near-surface composition, stratigraphy and structure – particularly with regard to resolving the internal layers of the polar caps' ice (See Fig. 6). The horizontal resolution of the instrument is between 0.3 and 3 km and the vertical resolution is around 15 meters (10 times better than with MARSIS). Comparison of Fig 5 and 6 gives a clear understanding of the better resolution that can be obtained at higher frequencies because of the associated increase in the frequency bandwidth.

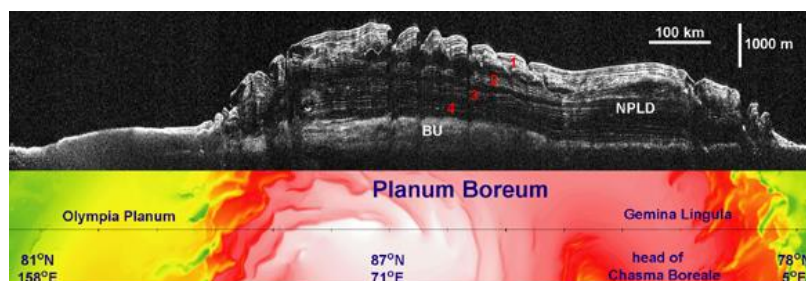


Image Credit: NASA/JPL-Caltech/University of Rome/SwR

Figure 6:

Top: SHARAD radargram of the North Polar Deposit Layers (NPLD) over the Basal Unit (BU)

Bottom: MOLA laser topography along the ground track

The future ESA/Roscomos ExoMars rover Mission [12] to Mars which is currently planned in 2018, will have onboard a ground penetrating radar designed to sound the very shallow subsurface (to a depth ~3 meters) along the rover path. This radar called WISDOM [41] is operating between 0.5 and 3 GHz and is thus able to provide a range resolution of few centimeters in the subsurface. It will provide information about the geological context and help to the identification of sites that might have been habitable and might have preserved potential traces of extinct or even extant life. The drill of the mission will then collect samples at a depth <2m that will be analyzed by a suite of instruments.

The following Mars2020 NASA has also selected a GPR to be part of its payload.

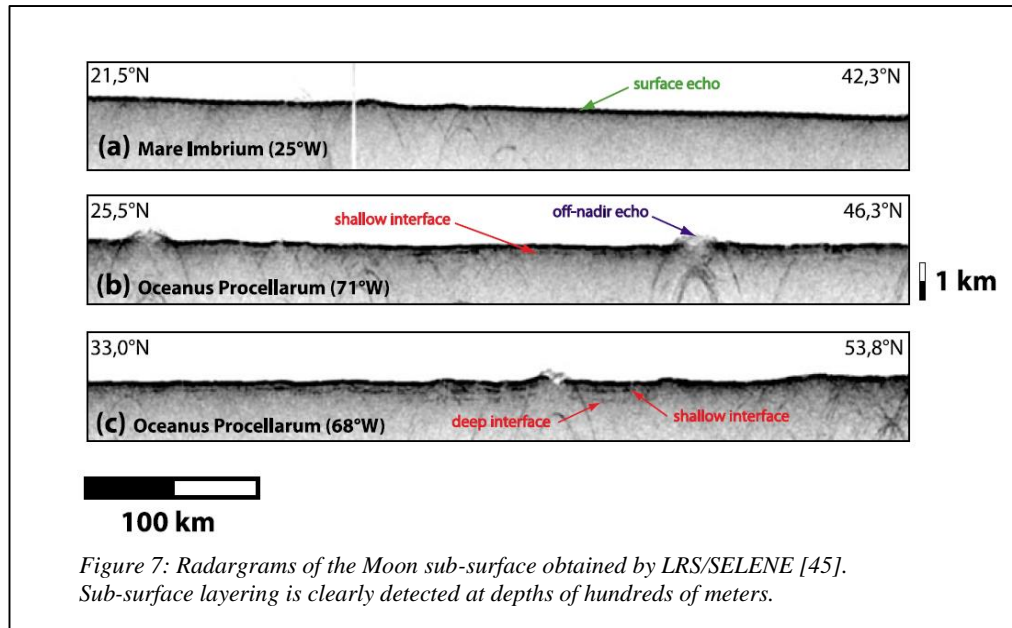
### 2.2.2. The Subsurface of the Moon

The NASA Explorer 35 bistatic experiment [42] was launched in 1967, its purpose was to study the electromagnetic reflective properties of the lunar surface. The experiment used the 136.10-MHz communication channel between the spacecraft and the Earth, the electromagnetic waves were scattered from the lunar surface and then recorded at Stanford on Earth. Statistics of the lunar surface's slope were obtained in the equatorial region.

The first successful attempt to sound the lunar subsurface from orbit was performed in 1972 during the Apollo 17 mission (ALSE experiment [43]). The measurements performed at 5 and 150 MHz allowed the detection of a layer at kilometeric depth in two sounded lunar maria and validated the feasibility of such measurements [44]. In 2007, the LRS



(Lunar Radar Sounder) instrument on-board the Kaguya spacecraft of the JAXA SELENE mission completed at 5 MHz a global coverage of the lunar surface and subsurface [45]. Subsurface features observed by both ALSE and LRS radars are interpreted as interfaces between lava flows of different ages (See Fig 7).



Two Mini-SAR (or Mini-RF) have been designed and used to explore the Moon [46], [47]. The first instrument was launched on the Indian Space Research Organization's (ISRO's) Chandrayaan-1 spacecraft while the second instrument was on-board the NASA's Lunar Reconnaissance Orbiter (LRO). They have mapped both Polar Regions and a number of different geologic units on the lunar surface. Mini SAR instruments have been designed to map the permanently dark areas of the lunar Polar Regions to search for potential water ice deposits. The search for water ice is their primary science objective, but they also characterized the surface roughness and thickness of the regolith. The Mini SAR transmits Right Circular Polarization at 2.5 GHz and receive both Left and Right which gives access to the circular polarization ratio. The elevated CPR observed within permanently shadowed craters in the polar areas are consistent with the presence of water ice in these craters.

### 3. Sounding the nucleus of comet Churyumov-Gerasimenko

Despite numerous observations of comets either from Earth or during dedicated space missions among which ESA's Giotto, NASA's Deep Space, Stardust and Deep Impact [48], there has been, prior to the Rosetta mission, no direct access to the structure of cometary nuclei. Therefore, any information about their internal structure would provide clues to better understand their accretion processes in the early solar system and their evolution. The successful Rosetta mission [49] with the recent descent and landing of Philae on the nucleus of 67P/Churyumov-Gerasimenko at the end of 2014 has provided for the first time in-situ data of the upper most importance.

With receivers and transmitters onboard both Rosetta and Philae, the objective of the CONSERT (Comet Nucleus Sounding Experiment by Radiowave Transmission) radar is the characterization of the nucleus in terms of internal structures and dielectric properties. CONSERT [50] is a bi-static radar that has been designed and built to probe the interior of the comet Churyumov-Gerasimenko's nucleus. The instrument consists of two separate units: The Lander CONSERT unit (LCN) located on Philae and the Orbiter CONSERT unit (OCN) located on the orbiter. A radio signal at 90 MHz is transmitted by the OCN and propagates through the comet nucleus to the LCN. The LCN works as a transponder: the signal received by the lander is analyzed in real time to detect the strongest echo (which is expected to be the first one) for synchronization purpose, and immediately retransmitted back to the orbiter, where the final data is eventually recorded. The propagation delay and amplitude of the received echoes measured are readily obtained from the measured impulse response.

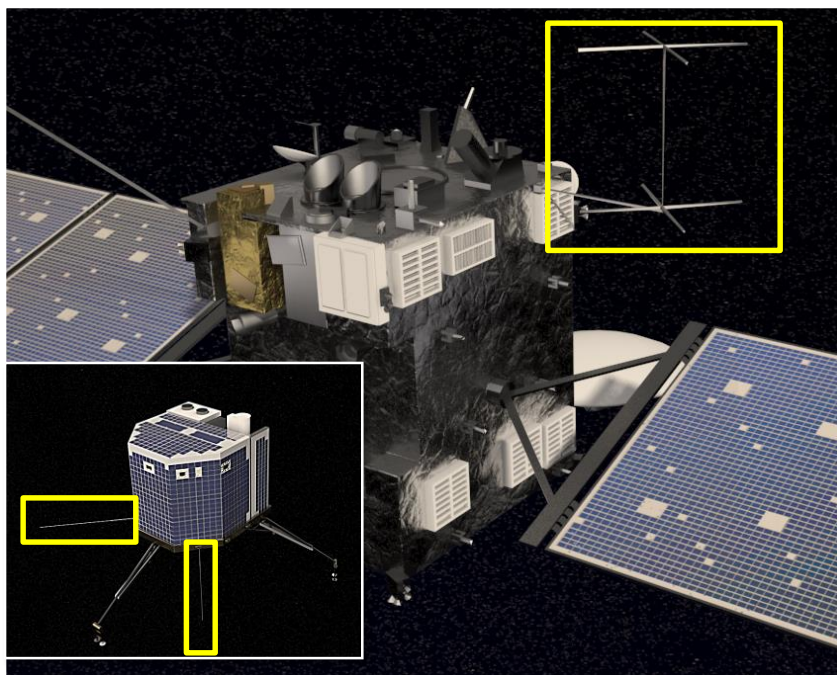


Figure 8: Mock-up of the Rosetta main spacecraft and of Philae. The antenna systems on the OCN and LCN are highlighted in yellow.

For each sounding configuration, the measured propagation delay corresponding to the first echo allows to estimate the average dielectric constant of the nucleus along the propagation path, and to constrain the composition and porosity of the nucleus. The width of the received echoes is an indirect measurement of the internal heterogeneity at a scale larger than the experiment wave length ( $\sim 3\text{m}$ ). The measured amplitude can be linked to attenuation and/or diffusion inside the nucleus. To actually process the data and qualitatively and quantitatively characterize the nucleus internal structure, an as accurate as possible knowledge of the experiment geometry (Orbiter and Lander location and attitude with respect to a 3D nucleus shape model) is needed. At the moment, the exact position of the Philae lander is still unknown which makes the data inversion quite complicated. CONSERT measurements have even been able to provide an estimate of the Philae location inside a strip of  $350 \times 30 \text{ m}$  at the surface [51]. Moreover, information about Philae's attitude with respect to its close environment suggests that it is not standing on its three feet, which causes a significant polarization mismatch between lander and orbiter's antenna. Nevertheless, some good quality data have been obtained. They show that the wave did propagate through some part of the nucleus and very preliminary analysis of the data show are consistent with the fact that scattering inside the nucleus is very limited [52].

Whenever the actual location and position of Philae can be better constrained, the thorough analysis and interpretation of the data collected CONSERT will be possible.

## Conclusion:

The brief overview demonstrates the essential contribution of radars to the exploration of the Solar System.

Radars can be highly adapted to different scientific objectives and future missions will have among their payload's instruments radars that have been specifically designed. Each of the next rover's missions to Mars (ExoMars and Mars2020) will accommodate a ground Penetrating radar to discover along the rover path the geologic features buried under the Martian subsurface. GPRs might soon become mandatory instruments on a rover payload just like cameras are at the moment. The synergy between these two context instruments is obvious and will give the possibility to have a really understanding of the site geological history and, for example, to assess its capacity to have been habitable in the past.

Juice mission will carry on-board a radar called RIME (Radar for Icy Moon Exploration) operating at 9 MHz. This ice penetrating radar has been designed to study the subsurface structure of the Jupiter's icy moons Ganymede, Europa and Callisto down to 9 km depth with vertical resolution of up to 30 m in ice.

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